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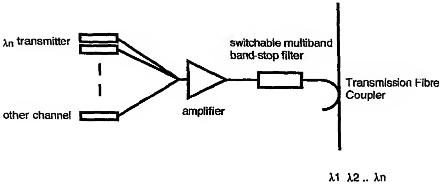
(54) Title: SIGNAL ADDITION TO A WAVE DIVISION MULTIPLEX SYSTEM



(57) Abstract: A telecommunications system is formed from a single mode optical fibre carrying Wave Division Multiplex (WDM) traffic, there being a transmission fibre coupler arranged to couple signals from channels to be added to the single mode optical fibre. There are also coupling means to connect the channels carrying the signals to be added to the input of an optical amplifier, the output of the amplifier being connected in series to the transmission fibre coupler by a switchable multiband band-stop filter arranged to pass only signals having the wavelength of a signal or signals to be added to the WDM traffic. The switchable multiband band-stop filter may be a fibre Bragg filter, a selectable stack of filters or an assembly of bleachable filters. A switchable multiband filter is formed from a stack of layers of a semiconductor bleachable medium whereby the bleaching threshold is that of each single layer and the attenuation is the sum of the transmissions through all the layers comprising the stack.

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Signal Addition to a Wave Division Multiplex System

Communications traffic is increasing year by year by around 100% in some areas due to internet, mobile telephony, interactive entertainment, video conferencing and communications, and information systems. Optical fibres are being operated with many different wavelength channels in wavelength division multiplexed (WDM) systems. These fibres are being used in communications networks in which traffic may be carried on different carrier wavelengths through several switching points. These optical networks may be constructed from optical WDM line systems connected by optical switches and from optical WDM rings interconnected to allowtraffic to be selectively switched between rings. A convenient way to construct such rings is from a basic building block at which wavelength traffic channels may be added or dropped from the ring. Such an equipment is called an Optical Add Drop Multiplexer for ring networks. Optical Add Drop Multiplexer functions are also used in WDM line systems to permit a fraction of the WDM channels to be dropped at intermediate points.

Adding and dropping of wavelength channels to a single mode fibre can be accomplished by means of broadband splitter/combiners such as fibre fused couplers or silica waveguides formed in pairs and run with small dimensional spacingless than a wavelength so that coupling between the optical fields occurs. When such couplers are used, splitting/coupling losses are very severe. For example, with two way coupling, loss is more than 50% and for 32 way coupling losses are more than 97%.

Alternatively coupling can be achieved using diffractive and dispersive elements to make wavelength division multiplexing combiners (WDM combiners). Such WDM combiners may have n input ports and one output port. To couple into the output port it is necessary to introduce each wavelength channel into its correct port. Such devices have, in practice, coupling losses between 1dB (~80%) to 7dB (~20%) depending on qualityand on band pass characteristics of the filtering of each channel.

A communications network becomes most economic when it becomes possible to load up all parts of the network and when it is possible to provide alternative 'protection' paths for traffic. This ideal is approached when traffic can be easily switched from one wavelength channel to another and when all switch interconnection options are available, ie when the switches are 'non-blocking'.

If wavelength changing is introduced it becomes necessary to have switches associated with the WDM combiners. Alternatively splitter/combiners can be used but then optical amplifiers become necessary to overcome the large losses incurred during the splitter/combiner functions. The amplifiers introduce 'noise' due to Amplified Spontaneous Emission (ASE) onto the traffic paths. This manifests as reduced optical signal to noise ratio (OSNR) in the optical signal carrying the communications traffic.

According to the present invention there is provided a telecommunications system comprising a single mode optical fibre carrying Wave Division Multiplex (WDM) traffic and including a transmission fibre coupler arranged to couple signals from channels to be added to the single mode optical fibre, further comprising coupling means to connect the channels carrying the signals to be added to the input of an optical amplifier, the output of the amplifier being connected in series to the transmission fibre coupler by a switchable multiband band-stop filter arranged to pass with low loss only signals having the wavelength of a signal or signals to be added to the WDM traffic and to attenuate all signals at wavelengths not having the wavelength of the signal or signals to be added to the WDM traffic.

There is further provided a switchable multiband filter comprising a stack of layers of a semiconductor bleachable medium whereby the bleaching threshold is that of each single layer and the attenuation is the sum of the transmissions through all the layers comprising the stack.

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figures 1(a) to 1(f) show methods by which traffic can be added at an optical add/drop-node;

Figure 2 shows the use of a switchable multiband band-stop filter;

Figure 3 shows a fibre Bragg switchable multiband band-stop filter;

Figure 4 shows a switchable multiband band-stop filter formed from a filter stack;

Figure 5 shows a switchable multiband band-stop filter formed from a diffraction grating stack; and

Figure 6 shows a switchable multiband band-stop filter formed using bleachable media

Figures 1(a) to 1(f) show methods by which traffic can be added at an Optical Add Drop Node and comments regarding each method are included:

Figure 1(a) shows a method where channels areconnected to a WDM multiplexer and then to a transmission fibre coupler. This method can be scaled to large numbers of channels (WDM couplers for 80 channels or more are available commercially today). The losses may be 3dB for a coupler and 3dB for a WDM multiplexer, a total of 6dB and do not change significantly with channel count (number of channels).

Figure 1(b) shows where the channels are connected to an n-way waveguide or a fibre splitter/combiner functioning as a coupler. There is a loss of 1/n due to the multiway coupler and a loss of ½ due to the transmission fibre coupler, a loss of 12dB for an 8-way coupler and 3dB for the transmission fibre coupler, a total of 15dB and losses rise rapidly with channel count.

Figure 1(c) provides a means to bypass the transmission coupler loss. This requires n off 2 x 2 switches between a pair of back-to-back WDM multiplexers at each channel add/drop, where n is the channel count.

Figure 1(d) shows how through traffic where required passes through a switchable filter. This filter is equipped to selectively attenuate each through wavelength channel and to

heavily attenuate or effectively block, selected channels from which traffic may have been dropped and/or onto which new traffic is to be added. Scaling to large channel counts results in linearly scaling losses with this arrangement if a broadband (non wavelength selective) combiner is used, so high power optical transmitters are necessary.

Figure 1 (e) shows how 'flexibility' can be provided, that is any wavelength can be added to any input port, if a WDM multiplexer, an optical switch and a transmission fibre coupler are used. The loss is 1/2x1/2x1/2 = 1/8. Currently low loss switches are expensive. The whole switch must be included to afford 'flexibility' even if only a few channels are required to be added. The switches may for example be 3-D type Micro-Electrical Machine in Silicon (MEMS) which scale to large port counts with low loss. The optical multiplexer may also have low loss for large channel counts. Hence this approach scales but total loss is still significant and the cost and complexity of such an implementation is large.

Figure 1 (f) shows how flexibility can be achieved with couplers as in Figure 1 (b) with an amplifier overcoming the splitter/coupler losses. As the channel count is increased so the gain has to be raised and the noise added to the added channels and to the "through" traffic increases.

To summarise:

Figure 1 (a) does not provide flexibility;

Figure 1 (b) introduces high loss and therefore requires higher power tunable laser sources;

Figure 1 (c) like Figure 1 (a) does not provide flexibility. It also requires switches with low cross talk;

Figure 1 (d) has the same problems as Figure 1 (b);

Figure 1(e) provides flexibility but requires an n by n switch which is not widely available and which has to be provided even when adding only one channel.

Figure 1(f) has an amplifier which overcomes the loss but it introduces amplified spontaneous emission noise into the path of the 'through' channels and so compromises the performance of the system.

The invention seeks to provide flexibility, gain to the source and suppression of the ASE noise.

It is proposed that wavelength channels are added using a waveguide or fibre coupler, an amplifier and a switchable multiband band-stop filter, as shown in Figure 2.

Traffic is coupled into the single mode fibre. It is amplified along with all the other channels. Noise is added because of the amplified spontaneous emission in the amplifier. The switchable filter is set up so as to pass only the wavelength channels to be added. The switchable filter elements are set to have high loss in the wavelength bands of the channels which are not being added. The filter than attenuates the broadband amplified spontaneous emission from the amplifier. This reduces the noise added to the 'through' traffic channels.

Numerical modelling has shown that attenuation of the ASE becomes important for bit rates of 2½ and 10Gbit/s and above when traffic is required to pass through several OADM nodes in a ring. The OSNR (Optical Signal to noise Ratio) of traffic passing through several (say 8) OADM nodes may be improved by several dB by using the switchable multiband band-stop filter. The use of the amplifier in the add channel path enables the number of add channels to be scaled to 32 and beyond. The amplifier allows lower power transmitter modules to be used. The switchable filter is required to attenuate the ASE by ~10dB to 15dB. Filter transmission loss for through channels of ~3dB would be viable.

This approach allows low power tunable laser based transmitters to be used to add up to 32 channels and more. The channels can be added as the traffic builds so equipment can be added and financed as required on a 'pay as you grow' basis – or a "partial provisioning

with growth as needed" basis.. For very large channel counts – 2 stages of combining, amplification and filtering may be used to keep the ASE within the limit to permit transmission through several nodes with acceptable signal to noise OSNR ratio.

The switchable multichannel filter may be implemented in one of a number of ways:

1) Fibre Bragg gratings, one for each channel, each grating tunable by temperature or strain. The fibre gratings have a bandwidth around half a wavelength channel spacing and can be tuned to pass or block the traffic. These fibre filters are produced to be arranged in a series configuration as shown in Figure 3. The temperature needs to be raised by around 40 degrees Centigrade to tune by 50GHz to allow traffic to pass or be attenuated. Alternatively, strain can be applied by means of a piezoelectric actuator or by magnetostriction. A specification for this type of filter is included in the tables below:-

Switchable Blocker Specification

	Specification	Comment
Optical Specifications		
No. of Channels	32	
Channel Spacing Frequency	100GHz	
λ range	1535.82-1560.61nm	
Switching Time	<1s	
Switching Range, Frequency	50GHz	~0.4nm
Blocking Range	>15dB	Additional to insertion loss in pass state. Over channel width as specified (27.5GHz).
Insertion Loss in pass state	<3dB	Note other channels may be any combination of pass or block. Over channel width as specified.
Dispersion in pass state	100ps/nm maximum	Over channel width as specified.
Flatness in band (pass state only)	0.5dB	Over channel width as specified.
Insertion Loss Uniformity	<1dB	Over 32 channels.
Channel Width	>λ 0.11nm	Centred on ITU channel (>27.5GHz total)

Mechanical Specifications		
Dimensions	180mm x 100mm x 25mm	
Electrical Specifications		
Power Consumption	<10W	
Environmental		
Temperature	0 to 70 degrees C	
Qualification	Relevant Telecordia	
Reliability	MTBF > 10^5 hours	
Vibration	Relevant ETSI and NEBS	

This filter requires the reflection to be electrically retuned. To permit a channel to pass the reflector grating has to be tuned to sit in the wavelength band between two channels. This is restrictive on the packing of channels into a particular band. Also it needs programming, calibration and temperature control..

2) A filter pack can be placed in the path of the wavelength channels as shown in Figure 4, actuators removing filters from the pack so as to allow passing of the wavelength channels to be added and the ASE in the bands of the other channels being attenuated. This is difficult to arrange mechanically and requires a precise fixed pass-band filter foe each channel.

3) Alternatively, diffraction gratings can be used and moved out of the beam as required or switched off if an active grating medium such as Lithium Niobate or Liquid Crystal or other electro-optic material is used as shown in Figure 5.

4) Following a combiner and an amplifier as shown in Figure 6, the signal is introduced into a wavelength dispersive system such as an Arrayed Wave Guide optical multiplexer as described by M. Smit and Dragoni or a diffraction grating based optical multiplexer. For example there is described the implementation in the diffraction grating demultiplexer case. The optical traffic is formed into a parallel beam incident on the diffraction grating in the optical arrangement. The diffracted beams are then imaged as separate channels on to a reversible bleachable optical medium backed by a reflective element. Where the optical intensity is high, i.e. when an add channel is present, the medium bleaches and becomes

transparent and the mirror surface behind reflects this wavelength back into the optical system which couples it back into the fibre where it is coupled by a circulator into the transmission fibre. When there is no add channel present the element blocks ASE noise at that wavelength.

An example of a bleachable medium is Erbium doped P_2O_3 glass. Erbium can have a high concentration in P_2O_3 glass. 1mm thick plate could have a few dB of loss. The radiative lifetime of erbium atoms is ~10^{-2} seconds so once bleaching has occurred, it would not distort the digitally modulated signal which may have pulse lengths ~sub nanoseconds. Alternatively suitable dyes in polymer films are potential media for this as long as bleach lifetimes are significantly longer than the bit period of the traffic being passed through the filter. Also semiconductor bleachable media comprising Cadmium Telluride, or Cadmium Mercury Telluride, or Indium Gallium Arsenide Phosphide clad between Indium Phosphide layers for a double hetero-structure layer could be used. Here the absorber would be a semiconductor with bandgap less than the photon energy of the traffic and the intermediate (cladding) layers will have wider band gaps. A particularly favourable bleachable material for this purpose is a multilayer stack of InP/InGaAs/InP/InGaAs in which the Indium Gallium Arsenide layers are made 0.02μm thick and the InP layers separating the InGaAs layers 0.01 to 0.03μm thickness. A materials specification is given in the table below:

Layer No.	Material (including grades)	Composition spec. (see below)	Thickness (nm)	Quantum Well Repeats	Dopant type and conc.	
22	InP		1000		p = 1 e 18	Tolerances :
21	GaInAs		20		NUD (nom. Undoped)	
4-20(even)	InP		15	8	NUD	Wavelength +/- 10nm
3-19(odd)	GaInAs		20	8	NUD	Thickness +/- 5 %
2	InP		10		n = 1 e 17	Doping +/- 20 %
1	InP		2000		n = 1 e 18	Mismatch < +/-500 ppm
Substrate	InP	S.I. and n+ substrate			n = 1 e 18	

The attenuation of ASE is increased by having more GaInAs layers – 10 is modelled to give 15dB attenuation for the reflection geometry described above. The GaInAs layer will bleach when power increases to ~100 w/cm^2. If each channel is imaged to a spot of 8μm diameter, then the bleach power will be ~50μw. With 4μ diameter spot size the bleach power would be ~12μw.

Instead of the diffractive grating an Arrayed Wave Guide (AWG) optical mux could be used. A transmission configuration having a mux and demux stage could also be used effectively. Then no circulator would be required but lower net attenuation (from the single pass through the bleachable layer) would result and no reflector would be required.

<u>Definitions</u>

ASE :- Amplified Spontaneous Emission –the added noise from an optical amplifier

AWG :- Arrayed Wave Guide- these are optical waveguides in a circuit designed for optical multiplexing and demultiplexing and use interference to achieve dispersive wavelength separation

MUX :- Multiplexing device- a device to combine several signal channels into one

OSNR :- Optical Signal to Noise Ratio

Channel :- This has been used to mean a modulated optical carrier from a single laser. The laser wavelength is selected to conform to a particular tolerance within a standard grid – the ITU 100GHz or 50GHz Standard Grids for example

Wavelength :- this has been used to embrace a particular value and the band of wavelengths within one channel

Traffic :- refers in general to the data and analogue signals being carried by the transmission system

Bleachable filter :- A filter which passes optical beams having power sufficient to change the material absorption with low attenuation and significantly attenuates beams of lower power density. It is necessary that the change in absorption is reversible and not brought about by actual damage such as physical hole burning.

References

M.K. Smit: "New focusing and dispersive planar component based on an optical phased array", Electronics Letters, vol. 24, no. 7, pp.385-386, Mar. 1988.

A.R. Vellekoop and M.K. Smit: "Four-channel integrated-optic wavelength demuliplexer with weak polarisation dependence", Journal of Lightwave Technology, vol. 9, no.3, pp.310-314, Mar. 1991.

C. Dragone: "An N x N optical multiplexer using a planar arrangement of two star couplers", Photonics Technobgy Letter, vol. 3, no. 9, pp.812-815, Sept. 1991.

CLAIMS

1. A telecommunications system comprising a single mode optical fibre carrying Wave Division Multiplex (WDM) traffic and including a transmission fibre coupler arranged to couple signals from channels to be added to the single mode optical fibre, further comprising coupling means to connect the channels carrying the signals to be added to the input of an optical amplifier, the output of the amplifier being connected in series to the transmission fibre coupler by a switchable multiband band-stop filter arranged to pass with low loss only signals having the wavelength of a signal or signals to be added to the WDM traffic and to attenuate all signals at wavelengths not having the wavelength of the signal or signals to be added to the WDM traffic.

2. A telecommunications system as claimed in Claim 1 wherein the band-stop filter is particularly arranged to attenuate signals which are generated as a result of Amplified Spontaneous Emission (ASE)

3. A telecommunications system as claimed in Claim 1 or 2 wherein the switchable multiband band-stop filter comprises a series of fibre Bragg grating filters.

4. A telecommunications system as claimed in Claim 1 or 2 wherein the switchable multiband band-stop filter comprises a stack of selective narrow band pass filters and actuator means to displace respective filters to pass selected channels.

5. A telecommunications system as claimed in Claim 1 or 2 wherein the switchable multiband band-stop filter comprises a stack of diffraction gratings wherein respective diffraction gratings can be removed or deactivated or activated to pass selected channels.

6. A telecommunications system as claimed in Claim 1 or 2 wherein the switchable multiband band-stop filter comprises an optical wavelength channel demultiplexer arranged to spatially separate wavelength components of the signal carried by the single mode fibre and a bleachable reflector arranged to intercept the separated wavelength components of the signal and to pass with low loss only signals having the wavelength of a signal or signals to be added to the WDM traffic and to attenuate all signals at wavelengths not having the wavelength of the signal or signals to be added to the WDM traffic.

7. A telecommunications system as claimed in Claim 6 further comprising a multiplexer arranged to recombine the traffic into the single mode optical fibre.

8. A telecommunications system as claimed in Claim 6 or 7 wherein the bleachable reflector comprises Erbium doped glass.

9. A telecommunications system as claimed in Claim 6, 7 or 8 wherein the bleachable reflector comprises a thermally activated bleachable medium.

10. A telecommunications system as claimed in Claim 9 wherein the thermal activation is provided by the optical signals.

11. A telecommunications system as claimed in Claim 10 wherein the thermal activation is provided the photon energy of the optical signals.

12. A telecommunications system as claimed in Claim 6 wherein the bleachable reflector comprises a semiconductor bleachable medium.

13. A telecommunications system as claimed in Claim 9, wherein the semiconductor bleachable medium comprises Cadmium Telluride, or Cadmium Mercury Telluride, or Indium Gallium Arsenide Phosphide or Indium Gallium Arsenide clad between Indium Phosphide layers for a double hetero-structure layer.

14. A telecommunications system as claimed in Claim 10 or 11 where the bleachable material is a stack of GaInAs layers between InP or wider gap InGaAsP layers, so

that bleaching threshold is that of each single layer and the attenuation is the sum of the transmission through the multiple layers.

15. A telecommunications system as claimed in Claim 7 wherein the multiplexer and demultiplexer comprise an Arrayed Wave Guide (AWG).

16. A telecommunications system as claimed in any one of Claims 6 to 15 further comprising an optical circulator.

17. A switchable multiband filter comprising a stack of layers of a semiconductor bleachable medium whereby the bleaching threshold is that of each single layer and the attenuation is the sum of the transmissions through all the layers comprising the stack.

18. A switchable multiband filter as claimed in Claim 18 wherein the bleachable material is a stack of GaInAs layers between InP or wider gap InGaAsP layers.

Figure 1(a)

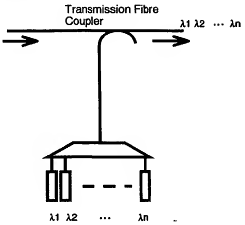


Figure 1(b)

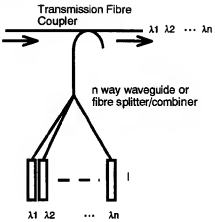


Figure 1 (c)

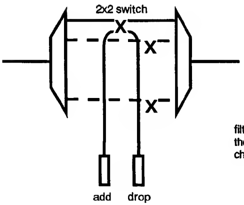


Figure 1 (d)

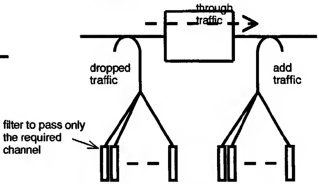


Figure 1 (e) Figure 1 (f)

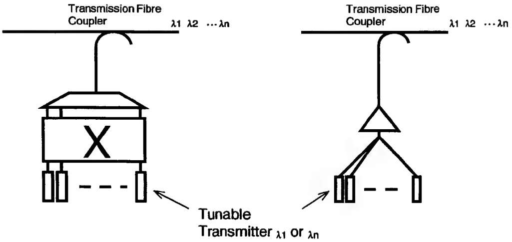


Figure 2.

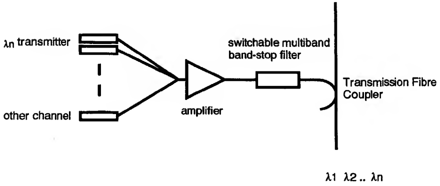


Figure 3.

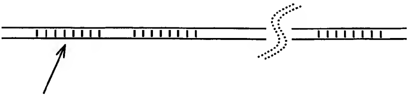


Figure 4.

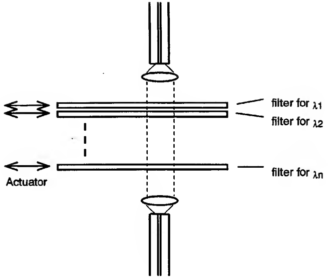


Figure 5.

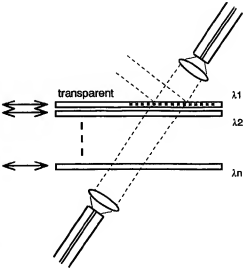
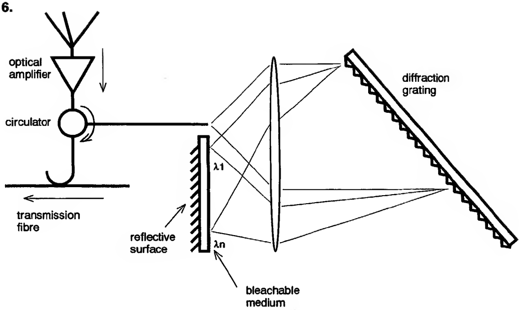


Figure 6.


optical
amplifier
circulator
transmission
fibre
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λn
bleachable
medium
diffraction
grating

INTERNATIONAL SEARCH REPORT

PCT/GB 02/00584

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04J14/02 G02F1/017

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04J H04B H04Q G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 10, 31 August 1999 (1999-08-31) & JP 11 127121 A (FUJITSU LTD), 11 May 1999 (1999-05-11)	1-16
P,X	-& US 6 278 536 B1 (KAI ET AL) 21 August 2001 (2001-08-21) abstract column 1, line 46 - line 51 column 22, line 4 - line 7 column 22, line 45 -column 23, line 61 figure 3 ---	1-16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
13 June 2002	26. 06. 02

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 948 153 A (FUJITSU LTD) 6 October 1999 (1999-10-06) abstract column 10, line 5 -column 13, line 16 figures 2 and 3 column 40, line 17 - line 27 column 46, line 40 - line 43 ---	1-16
A	EP 0 967 752 A (JAPAN TELECOM CO LTD; SUMITOMO ELECTRIC INDUSTRIES (JP)) 29 December 1999 (1999-12-29) abstract column 6, line 9 -column 7, line 33 figure 3A column 10, line 9 -column 11, line 5 figure 9 ---	1-6
A	EP 0 944 192 A (ALPS ELECTRIC CO LTD) 22 September 1999 (1999-09-22) the whole document ---	1-16
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 02/00584

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [X] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[X] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-16

   A telecommunications system

2. Claims: 17, 18

   A switchable multiband filter

INTERNATIONAL SEARCH REPORT
Information on patent family members

PCT/GB 02/00584

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